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Biofouling : a means of aquatic species transfer

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BIOFOULING : A MEANS OF AQUATIC SPECIES TRANSFER

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1 INTRODUCTION

Ships carry seawater in their ballast tanks when they are not fully loaded with cargo, in order to maintain adequate trim, draught and stability, adjust list and limit stresses on the hull. It is now well documented that the water pumped into the ship contains aquatic organisms – which can also sink to the sediments at the bottom of tanks – and that these organisms are thereby transferred from the port of origin to the destination. But it is seldom mentioned that aquatic organisms are also found on the outside of ships, attached on their hulls and appendages, as a result of **a very dynamic process called 'biofouling'**.

When comparing the two main introduction pathways associated with ships, namely ballast water and biofouling, some scientists (Drake & Lodge, 2007) regard biofouling as presenting **a higher risk of species introduction than ballast water**. However, predominance of invasive species vectors appears to differ for different regions (Gollasch, *et al.*, 2010).

2 WHAT IS BIOFOULING?

Biofouling is defined as the "accumulation of aquatic organisms such as micro-organisms, plants, and animals on surfaces and structures immersed in or exposed to the aquatic environment. [It] can include microfouling and macrofouling" (IMO, 2011). Indeed, when a clean surface is immersed in natural seawater, it immediately starts to adsorb a molecular 'conditioning' film primarily consisting of dissolved organic material (Jain & Bhosle, 2009).

There are more than 4,000 marine fouling species (Arai, 2009). For some, the settlement on a hard surface represents a transitory phase in their life-cycle, whereby they shift from larval stage to adult life (Callow & Callow, 2002).

The below Table provides some examples of micro- and macrofouling organisms (Table 1).

Picture source: http://www.seos-project.eu

Table 1: Some examples of microfouling and macrofouling organisms (Sources: Callow & Callow, 2002; Railkin, 2004; Ministry of Agriculture and Forestry Biosecurity New Zealand, 2010a; Ministry of Agriculture and Forestry Biosecurity New Zealand, 2010b; Sorte, Williams & Zerebecki, 2010)

		TYPES	EXAMPLES
MICROFOULING ORGANISMS		Sessile bacteria	*Micrococcus, Pseudomonas*
		Diatoms	*Amphora* spp., *Navicula* sp., *Nitschia* spp.
		Micro-fungi	
		Heterotrophic flagellates	*Monosiga*, *Pteridomonas*
		Sarcodines	
		Sessile ciliates	
MACROFOULING ORGANISMS	***Hard fouling***	Barnacles	*Amphibalanus amphitrite, Amphibalanus reticulatus, Balanus amphitrite*
		Bivalves	*Crassostrea gigas, Mytilus* spp., *Perna canaliculus*, *Perna perna*
		Calcareous tube worms	*Hydroides albiceps, Hydroides elegans*
	Soft fouling	Algae	*Laminaria* spp. (brown alga) *Enteromorpha* spp., *Ulva* spp. (green algae) *Ahnfeltia* spp. (red alga)
		Anemones	*Haliplanella* sp.
		Ascidians	*Didemnum vexillum*
		Bryozoans	*Bugula neritina*, *Cryptosula pallasiana*, *Watersipora subtorquata, Zoobotryon pellucidum*
		Corals	
		Hydroids	*Obelia* sp.
		Sea cucumbers	
		Sponges	*Acanthella cavernosa*

It should be noted that biofouling is not purely made up of sessile organisms. It may include **mobile organisms** as well, such as crustaceans and fish (Gollasch, 2002; Ministry of Agriculture and Forestry Biosecurity New Zealand, 2010b).

Figure 1: Biofouling is an assemblage of both sessile and mobile species
(Source: Ministry of Agriculture and Forestry Biosecurity New Zealand, 2010b).

Marine organisms congregate on surfaces by a five-stage process (Callow, 2000; Zinn, Zimmerman & White, 2000; Callow & Callow, 2002; Quiniou & Compère, 2009):

- **Attachment of organic and nitrogen-based compounds, as well as salts and silica, on the surface**.

  This phase lasts a few minutes. The result is that the surface becomes organically enriched with chemical compounds which occur naturally in seawater.

- **Attachment of primary colonizers, such as bacteria, algal cells and spores.**

  This phase takes place within a few hours. Organisms are attracted to the surface because it offers them a source of food.

- **Excretion of extracellular polymeric substances (EPSs) by the primary colonizers.**

  EPSs consist of lipids, proteins, nucleid acids, and polysaccharides. They play an important role in biofilm formation because they constitute the substratum in which micro-organisms will be encased (Flemming, *et al*., 2000; Ahimou, *et al*., 2007).

- **Development of a biofilm.**

  The biofilm matrix is generated within a few days up to a month through cell divisions. It is composed of myriads of bacteria, protozoa, larvae, algal cells such as diatoms, and spores, separated by interstitial voids filled with water (Lewandowski, 2000). This structure, which can be up to 500 μm thick, is also known as 'microfouling' or 'slime' (Callow & Callow, 2002).

  Both the internal cohesion and the adhesion of the biofilm to the colonized surface depend upon the nature and the amount of EPSs (Ahimou, *et al*., 2007). It is noteworthy that, **when structured in a biofilm, cells are less susceptible to biocides** than in their planktonic form (Allison, *et al*., 2000; Flemming, 2002; Russell, 2003). The reason is that the EPS matrix acts as a physical barrier that protects biofouling communities (Donlan, 2000). Furthermore, the biofilm provides a substratum for macroorganism attachment.

- **Accumulation of macro-organisms onto the biofilm.**

  Macrofouling organisms are comprised of 'hard fouling' organisms and 'soft fouling' organisms – see Table 1 (Callow & Callow, 2002).

  Some fouling organisms such as barnacles, mussels and tube worms are generally found on the lower parts of the ship's underwater body, while algae commonly occupy the higher parts (Ministry of Agriculture and Forestry Biosecurity New Zealand, 2010b). Algal growth depends on light quantity and availability of space (Holmström & Kjelleberg, 2000).

Several factors, both **operational** and **environmental**, influence the above-detailed process:

- Type, colour, age and state of the antifouling coating, ship speed, trading area (Swain, *et al*., 2006; Drake & Lodge, 2007; Schultz, *et al*., 2011).
- Type of biofilm matrix, competition and predation among fouling communities (Callow & Callow, 2002), temperature, pH and nutrient transfer within the biofouling layers.
- Abiotic environmental aspects as temperature, solar radiation and salinity further have large impacts on species survival (e.g. Kim & Micheli, 2013; Verween, *et al*., 2007), this specially regards ships travelling between tropic areas and colder areas or between seaports and freshwater ports.

In the early stages, organisms are easy to remove. As time goes by, they stick fast and accumulate. On some ships and in certain areas of the hull, it has been found that biofouling could reach a thickness of 30 cm (Gollasch, 2002).

3 BIOFOULING OF SHIPS AND POTENTIAL IMPACTS

Marine organisms congregate not only on the outside of ships and appendages – e.g. hulls, sea-chests, propellers, bow and stern thrusters, but also inside ships – such as on filters, heat exchangers, seawater cooling pipes, pumps and valves.

Sea-chests have lately been suggested to be hotspots for biofouling (Coutts and Taylor, 2004; Coutts and Dodgshun, 2007; Sylvester and MacIsaac, 2010, Frey *et al*., 2014). These are protected, cavity-like structures, built into the hull of a vessel and typically covered with metal grates (Coutts *et al.*, 2003) and are typically characterized by relatively low water flows compared to higher velocities and shear stresses experienced on the exposed, flat surfaces of the hull. As a result sea-chests provide a relatively protected refuge for many fouling organisms, leading to increased survivorship and thriving communities (Coutts and Dodgshun, 2007).

It is noteworthy that all vessel categories are affected by biofouling, i.e. warships, merchant ships, fishing vessels, barges, mobile offshore units, recreational boats, etc.

Biofouling of ships is a concern for safety, economic, and environmental reasons.

Safety impacts

Biofouling may compromise safety because it hampers the proper functioning of pipework and associated appliances – for example, cooling systems, as well as the operation of navigation instruments (Callow, 2000).

Marine biofouling also accelerates biocorrosion (Meesters, *et al*., 2003), by maintaining a continuous metal/organisms interaction, which may result in the deterioration of some ships' structures.

Economic impacts

Biofouling reduces heat transfer, makes the ship heavier, and induces greater frictional resistance on the hull and the propeller, thereby reducing fuel efficiency (Schultz, *et al*., 2011). As an example, an increase of 100 μm in the average hull roughness augments fuel consumption approximately by 6 % (Arai, 2009).

To prevent the attachment of marine organisms, antifouling coatings have to be applied over the outside of ships. This includes removing the old coating, then repainting the hull and appendages.

Further maintenance operations might have to be carried out also inside ships – through the use of chlorine, for example (Meesters, *et al*., 2003) – when the water flow is reduced in pipes.

In-water inspections and cleaning, as well as drydocking, generate additional costs (Callow & Callow, 2002). Removal of biofouling on ships can be executed either at predetermined intervals or when the degree of fouling makes it necessary – such as in the U.S. Navy ships (Schultz, *et al*., 2011). Cleaning techniques involve water jets, steam, robots with rotating brushes, ultrasound or acid and base baths. It should be noted that not all methods are applicable to large vessels and mobile offshore drilling units (Zinn, *et al*., 2000).

Environmental impacts

Biofouling might present an equivalent or even greater risk of species transfer than ballast water (Drake & Lodge, 2007), however, other studies found that ballast water is the dominating vector. Despite the application of antifouling coatings, organisms are still found on ships. They accumulate in niche areas, as well as on the surfaces where the coating is damaged, worn or inadequately applied.

As it generates frictional resistance when the vessel moves through the water, biofouling increases bunker fuel consumption, and in turn, CO_2 emissions (Zinn, *et al*., 2000; Callow & Callow, 2002; Drake & Lodge, 2007; IMO, 2010).

4 HOW TO REDUCE BIOFOULING OF SHIPS?

Antifouling coatings

Historically, antifoulants included biocides such as lead, arsenic mercury and their organic derivatives. However, these were banned due to the environmental risks that they posed. Also the revolutionary self-polishing copolymer technique that employed a similar heavy metal toxic action to deter marine organisms, the antifoulant tributyltin (TBT), has been banned. Indeed, the use of **organotins** in antifouling paints was prohibited in 2008, with the entry into force of the International Convention on the Control of Harmful Antifouling Systems on Ships, 2001 (AFS Convention). (See chapter 6 for international biofouling management measures.)

Since 2008, two broad categories of antifouling coatings are applied on ships: those which contain toxic agents, and those that do not. The former category makes use of biocides, such as **copper** associated with booster biocides. The working principle of such paint systems is based on slow release of toxins in time (self-polishing coatings). Copper has been used for a long time as an antifouling agent (Callow & Callow, 2002). The latter, is based on biocide-free products such as silicone-based antifouling paints. A diversifying market for antifouling systems is to be expected as there is no single best solution for all ship types.

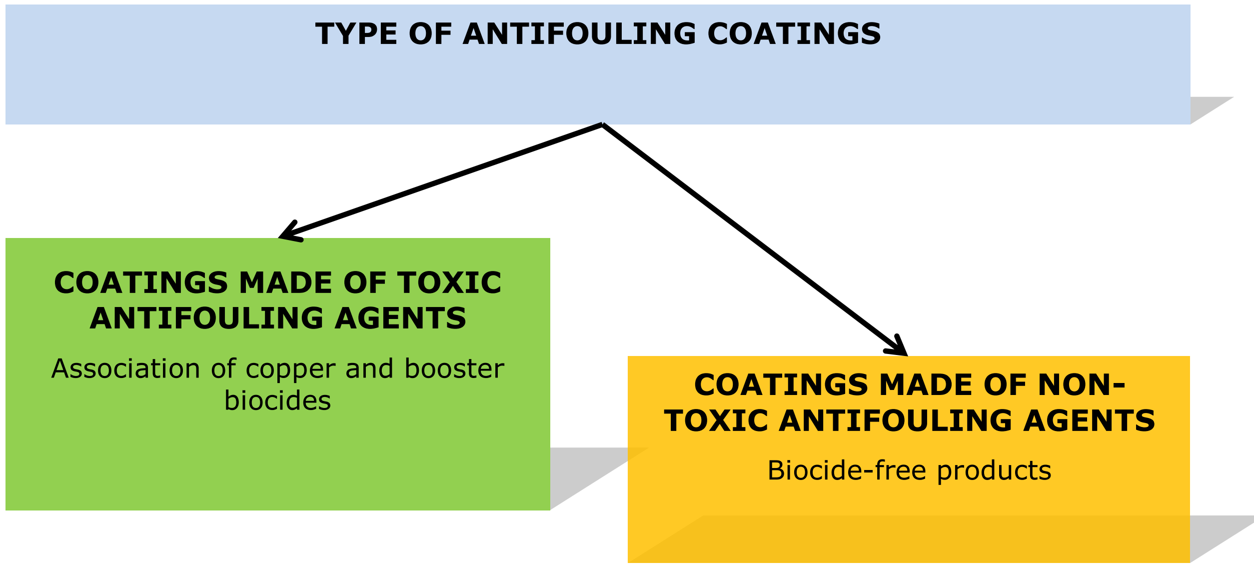

Figure 2: Two broad categories of antifouling coatings are applied on ships.

Non-toxic antifouling agents

Non-toxic paints may have a shorter lifespan than organotin paints and, consequently, may need to be applied more often (Champ, 2001; Readman, *et al*., 2002; Chambers, *et al*., 2006).

They might also be less efficient in preventing biofouling (Mineur, *et al*., 2007). Another drawback of biocide-free coatings is that they may not be sufficiently robust for some deep-sea ships (Callow, 2000).

Non-toxic, fouling-resistant coatings are based on polymers designed to minimize molecular adhesive forces between the adhesives used by marine organisms and the coating. This is made through manipulation of the physicochemical and/or materials properties of the coating. In order to be able to select a surface it is necessary to understand the interfacial interactions at the molecular level. As a result, a great challenge is the vast diversity of fouling organisms and the range of their adhesion mechanisms (including adhesives) (Callow & Callow, 2011).

Natural antifouling surfaces further inspire researchers whilst searching for new coating designs. For example, marine invertebrates such as sponges and corals usually remain remarkably free from settlement by fouling organisms. Indeed, sponge-derived anti-fouling molecules have been found to inhibit the settlement of barnacle larvae (Hellio, *et al*., 2005), inhibit fouling by macroalgae (Kubanek, *et al*., 2002), or repel the blue mussel *Mytilus edulis galloprovincialis* (Sera, *et al*., 1999). There is much research to be done within this field.

Hull maintenance

Both biocidal and biocide-free antifouling coatings may contain harmful substances that pose a contamination risk if released into the environment. Therefore, application, maintenance and removal of anti-fouling coatings on vessels in maintenance facilities/dry-docking or in-water can result in contamination of the aquatic environment. For example, toxic paint particles can be released into the marine environment if ship hull cleaning procedures are improperly regulated and contained, and the release of biofouling organisms during cleaning can facilitate the spread of invasive aquatic species. Decisions on the appropriate management option for a specific ship will be influenced by many factors, including the species present, the level of fouling, and the time a vessel spends in a recipient region (Hopkins & Forrest, 2008).

5 POSSIBLE SIDE-EFFECTS OF SHIPS' BIOFOULING CONTROL METHODS

Leaching of biocides contained in antifouling coatings

The use of **organotin compounds**, such as tributyltin (TBT), in antifouling paints has produced damaging effects on marine life. In the 1980s, it was discovered that TBT can cause gastropods and bivalves morphological disorders and a stop in reproduction (Alzieu, 2000; Santos, *et al*., 2002). It also has deleterious effects on fish immune system, thereby increasing fish susceptibility to pathogen infections (Nakayama, *et al*., 2009).

Despite the ban declared by the International Convention on the Control of Harmful Antifouling Systems on Ships, 2001 (AFS Convention), TBT will remain a concern for several years because this antifouling biocide accumulates in sediments (Bray, 2006; Langston, *et al*., 2009), which might be re-suspended at one time or another. TBT has a decades long decomposition time, in particular in temperate and cold climates and when in the sediment. High concentrations of TBT have been found worldwide in the vicinity of ports, even in remote areas. For example, in mussels collected near harbors of northern Norway (Kannan & Tanabe, 2009). The 'imposex' phenomenon – i.e. male characteristics appearing in female individuals – has been observed on mussels and snails from the coasts of e.g. Norway, Iceland, the Faroe Islands and Svalbard (OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic, 2000). TBT contamination has also been recorded in Antarctic marine sediments (Negri, *et al*., 2004). Imposex, along with high levels of TBT and metabolites, has further been demonstrated in densely shipped seas, and the imposex incidence was correlated with the number of ships passing in the vicinity (e.g. ten Hallers-Tjabbes, *et al*., 1994; ten Hallers-Tjabbes *et al*., 2003).

The biocidal antifouling agents used since 2008 may also impose problems on the environment and on non-target species. Indeed, even though Cu, which is the biocide of choice for present-day antifouling paints, is an essential micronutrient used in enzymes involved in several metabolic processes, the metal may negatively affect organisms at concentrations higher than physiologically necessary. It has been found that Cu from antifouling paint is an important anthropogenic source of Cu to the aquatic environment and that it in marine environments often exceeds water quality criteria (e.g. Srinivasan. *et al*., 2007). Apart from the toxicity of copper, synergistic effects when combined with booster biocides may be a problem (e.g. Bao, *et al*., 2013).

6 INTERNATIONAL BIOFOULING MANAGEMENT MEASURES

International measures

In 2011, the Marine Environment Protection Committee (MEPC) of the IMO adopted the voluntary 'Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species' (IMO, 2011). A separate guidance document, based on these Guidelines, provides advice relevant to owners and/or operators of recreational craft less than 24 metres in length, using terminology appropriate for that sector. These guidelines represent the first international action addressing ships' biofouling. The intended goal is to reduce the accumulation of micro- and macro-organisms on the outside of ships by choosing the **appropriate coating**, by conducting **in-water inspections and cleaning**, as well as **proper removal during drydocking**. Ships are required to follow a biofouling management plan and to keep a record book. The guidelines also provide recommendations for the management of **biofouling waste** in land-based facilities. The guidelines will be non-mandatory and as such are not legally enforceable at a global level. However, it is possible that some countries will implement the provisions in the guidance (or parts of them) into national law to protect their waters from invasive marine species from biofouling on ships (IMO, 2011).

In February 2013, the BLG Sub-Committee drafted a guidance document for evaluating the effectiveness of the 2011 Guidelines for the control and management of ships' biofouling. The objective of this initiative is to provide a thorough mechanism for ensuring that the 2011 Biofouling Guidelines are being implemented.

7 EXAMPLES OF SPECIES INTRODUCED INTO THE NORTH SEA THROUGH SHIPS' BIOFOULING

Didenmum vexillum

Didenmum vexillum is a bottom dwelling tunicate native to the waters around Japan. It has however been reported as an invasive species in a number of places in Europe and North America. This species can attach and build over most substrates and will even grow over other organisms when it needs more room to expand (e.g. Bullard *et al*., 2007; Auker and Oviatt, 2008; Gittenberger, 2007; Valentine *et al*., 2007; Dijkstra and Harris, 2009). This trait makes it a competitor for resources (e.g. suitable attachment substrates, food, etc.). Its appearance has given rise to its common name marine vomit. Interestingly, this species is not only confined to disturbed and polluted areas, but is also common in the more clean waters why its invasions potentially might have implications on industries in "cleaner" waters, such as fisheries and aquaculture (Bullard et al. 2007; Valentine et al. 2007), and may further impact natural ecosystems by altering the local habitat (Bullard et al. 2007; Valentine et al. 2007).

Didenmum vexillum
U.S. Geological Survey/photo by Dann Blackwood

Dasya baillouviana

Dasya baillouviana is a red macroalga. It is a bottom-dweller that usually grows to a length of 50-75 cm. Reproduction can be either asexual or sexual, the latter being more common. Its reproductive cells do not have flagella and it is considered passive because it is not capable of propelling itself in the water and is carried by oceanic currents. *D. baillouviana* can also grow on the shells of bivalves, such as oysters (Haydar & Wolff, 2011) and may therefore compete with other species of algae for space to grow on solid materials. Fertile plants of *D. baillouviana* can develop in just six weeks. *D. baillouviana* is native of the Mediterranean Sea – in particular, along the coasts of Corsica (Coppejans, 1979), the Black Sea – Russian shelf area (Anonymous, 2008) and the Atlantic coast of the United States (Hay & Sutherland, 1988). *D. baillouviana* appeared for the first time in the North Sea at the beginning of the 1950s, in Dutch coastal waters (Stegenga & Prud'homme Van Reine, 1999; Wolff, 2005). Its presence in the Skagerrak was reported along the Swedish west coast in 1953, in Denmark in 1961, and along the south coast of Norway in 1966 (Hopkins, 2002). The species was present in Danish waters in the 1990s (Nielsen, 2005). In 1999, very large specimens of the species were observed in the Kattegat, growing in areas where warm water was discharged by a nuclear power plant (e.g. ICES, 2000; Nyberg, 2007). *D. baillouviana* was spotted in Germany in 2002 (ICES, 2006). It is not sure whether the species was transported from the Western Atlantic through shipping (Hopkins, 2001; ICES, 2006; Gollasch, *et al*., 2009) or aquaculture activities (Reise, *et al*., 1999; Wolff, 2005).

Dasya baillouviana growing on the shells of mussels.
Photo: Annelie Lindgren, Dep. of Marine Ecology, Gothenburg University.

<u>*Elminius modestus*</u>

Elminius modestus is a marine crustacean, a benthic suspension feeder, of the subclass Cirripedia, whose diameter usually measures between 5 and 10 mm. The outside of the shell is flat, and of a white to grey - sometimes darker - colour (OECD, 1963). *E. modestus* can survive up to ten days outside water, tolerates low or variable salinity levels, turbid conditions, low temperatures and even pollution (Crisp, 1958; JNCC, 2012). This barnacle has a high fecundity and a physiological optimum above 20°C (Witte, et al., 2010). *E. modestus* can be found in large numbers on piers, pilings, ships, buoys, stones and even seaweeds in sheltered areas and estuaries. It is less abundant in areas influenced by ocean currents (OECD, 1963). This crustacean rapidly outnumbers native species, such as *Balanus balanoides*, and competes for space with them (Crisp, 1958). *E. modestus* is native of the southern Pacific, particularly of Australia and New Zealand (OECD, 1963; Reise, *et al*., 1999; Hopkins, 2001; Kerckhof, *et al*., 2007). It was transported from the Southern Pacific to the United Kingdom on ships' hulls (OECD, 1963; Gollasch, *et al*., 2009) and possibly in ballast waters during larval stage (Hopkins, 2001; JNCC, 2012). It was first recorded in 1945 in Chichester Harbour, United Kingdom (Crisp, 1958; Reise, *et al*., 1999). *E. modestus* then spread to France, Belgium, the Netherlands, Germany and Denmark, by both marginal and remote dispersal - i.e. larval drift, favoured by an eastward current, and transfer by ships (Crisp, 1958; Drévès, 2001; Wolf, 2005; Kerckhof, *et al*., 2007). In addition, *E. modestus* was unintentionally introduced into French bivalve farming areas through the importation of cultivated bivalve molluscs (Pigeot *et al*., 2001). Although it remained scarce during many years, it developed quickly and outnumbered native barnacles from 2007 onwards. Modelling studies on the effects of climate change and rising temperatures predict that *Elminius modestus* is likely to extend its range in the years to come (Reid *et al*., 2009).

Elminius modestus, here on wood.
Photo: Christian Buschbaum.

Ficopomatus enigmaticus

Ficopomatus enigmaticus is an invertebrate of the class Polychaeta. The tubeworm grows between 1.5 and 2 cm per month and produces a calcareous tube that serves as a protection (Camus, *et al*., 2000). Tubes bind together and form reefs which can reach up to several decimeters in thickness (Camus, *et al*., 2000), and up to 13 kg in weight in three months (ICES, 2009). This species is highly tolerant to variations in its environmental conditions. Although the invertebrate is generally found in brackish waters (Wolff, 2005; Gollasch, et al., 2009), where it has an optimal growth, it can nevertheless tolerate a salinity ranging from 5 to 55 PSU. *F. enigmaticus* can withstand temperatures between 0°C and 35°C and tolerate a pH ranging from 4 to 9. The reproduction and growth of *F. enigmaticus* seem to depend on nutrient abundance, low salinity and weak currents. Indeed, the mechanical action of waves may hamper its development (Schwindt, *et al*., 2004a). *F. enigmaticus* is considered to be an 'ecosystem engineer' inasmuch as it can have physical impacts on natural systems (Schwindt, *et al*., 2004b). The species builds reefs whose shape may depend on water depth, water flow direction and the nature of the surface upon which the tubes are attached. When these reefs combine to form one single circular structure, the whole can measure up to 7 m in diameter and 0.5 m in height. It gives shelter to thousands of individual *F. enigmaticus* but also to other species (Schwindt, *et al*., 2004b). Reef expansion may result in geomorphologic and hydrodynamic alterations in the receiving environment (Schwindt, *et al*., 2004a). In addition to environmental impacts, the development of *F. enigmaticus* can result in pipe clogging, as well as fouling of port infrastructure and ship hulls (Camus, *et al*., 2000 ; ICES, 2000, 2006, 2009). *F. enigmaticus* is native of the Indian Ocean and Southern Pacific (Reise, *et al*., 1999 ; Hopkins, 2001; Wolff, 2005 ; ICES, 2009). *F. enigmaticus* was observed in France, in 1921 (Camus, *et al*. 2000 ; ICES, 2000, 2009), soon after in United Kingdom in 1922 (Gollasch, et al., 2009) and in the Netherlands in 1968 (Wolff, 2005). The polychaete was also reported in Denmark (ICES, 2009). It is considered established in United Kingdom, Germany, the Netherlands (Wolff, 2005) and Belgium (Gollasch, *et al*., 2009). It is unclear whether *F. enigmaticus* was introduced by shipping (Reise, *et al*., 1999 ; Hopkins, 2001 ; Wolff, 2005) or aquaculture activities (Gollasch, *et al*., 2009).

Ficopomatus enigmaticus.
Photo credits: Museo di Storia Naturale di Venezia.

Laminaria ochotensis

Laminaria ochotensis is an edible brown alga (kelp) of the kingdom Phaeophyta which grows at a water depth of about 3 to 10 m (Miyabe, 1902). *L. ochotensis* lives naturally along the coasts of Japan (Wallentinus, 2002; Selivanova, *et al*., 2007). The species has been observed in Germany and its introduction has been attributed to hull fouling (Selivanova, *et al*., 2007; Gollasch, *et al*., 2009).

8 CONCLUSION

The issue of alien species translocation in biofouling is being dealt with in IMO Guidelines. The existing IMO Guidelines however need to be updated regarding for example niche areas on ships, such as sea chests, as these enclosed small spaces with lack of effective antifouling paints and elevated temperatures provide suitable conditions for a variety of species and larger adult marine organisms that might not survive on a hull surface or in ballast water.

Policy makers and others involved in developing policies for biofouling have spent ample thoughts on a feasible form for regulating biofouling. The question is would it best fit under another Convention, notably the Anti-Fouling Convention (2001) or the Ballast Water Management Convention (2004), or be a self-standing instrument?

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